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## Abstract

We present two new rapidly oscillating Ap (roAp) stars, TIC198781841 and TIC 229960986, discovered in TESS photometric data. The periodogram of TIC198781841 has a large peak at 166.506day$^{-1}$ (1.93mHz), with two nearby peaks at 163.412day$^{-1}$ (1.89mHz) and 169.600 day$^{-1}$ (1.96mHz). These correspond to three independent high-overtone pressure modes, with alternating even and odd $\ell$ values. TIC229960986 has a high-frequency triplet centered at 191.641day$^{-1}$ (2.218mHz), with sidebands at 191.164 day$^{-1}$ (2.213mHz) and 192.119day$^{-1}$ (2.224 mHz). This pulsation appears to be a rotationally split dipole mode, with sideband amplitudes significantly larger than that of the central peak; hence, both pulsation poles are seen over the rotation cycle. Our photometric identification of two new roAp stars underscores the remarkable ability of TESS to identify high-frequency pulsators without spectroscopic observations.



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## 1. Introduction

The Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2015) has revolutionized the field of asteroseismology with its short-cadence observations of over 200,000 stars during its Prime Mission, from 2018 July to 2020 July (Guerrero et al. 2021). Of particular note are the rapidly oscillating chemically peculiar A (roAp) stars, whose high-frequency pulsations are easily identified using a continuously observing, short-cadence space probe like TESS or Kepler that can produce a light curve with a high signal-to-noise ratio.

First discovered through targeted observations by Kurtz (1982), roAp stars are a subclass of the Ap stars, which are strongly magnetic and exhibit enhanced abundances of rare earth metals (Preston 1974). roAp stars additionally exhibit high-overtone pmode pulsations, with periods in the range 4.7–25.8minutes ($\nu$=55–310 day$^{-1}$). Tens of new roAp stars have been identified from recent large-scale space- and ground-based photometric surveys (see Holdsworth 2021 and references therein).

Much remains unexplained about these stars, however. Certain roAp stars pulsate at frequencies higher than those suggested by models (see, e.g., Cunha et al. 2013), perhaps due to their pulsations being excited by a different mechanism than the typical $\kappa$mechanism. Moreover, there have been roAp stars discovered that are cooler than the theoretical boundary of the instability strip, along with a pronounced dearth of stars toward the blue (hotter) edge of the instability strip (Cunha et al. 2019). By finding more roAp stars, large surveys such as TESS can provide the statistics to determine the underlying cause of this discrepancy—perhaps either from an observational bias or lower amplitudes in the pulsations of hotter stars.

## 2. Observations and Data

TIC198781841 was observed at 2 minutes cadence during TESS Sector40, from 2021 June 24 to 2021 July 23. It was also observed during Sector14 at 30 minutes cadence in the full-frame images; however, the Nyquist limit of this data inhibits us from studying the high frequencies at which roAp stars normally pulsate. The 2 minutes cadence light curve for Sector 40 was generated by the Science Processing Operations Center pipeline at NASA Ames Research Center (Jenkins 2015).

TIC229960986 was observed in 2 minutes cadence during TESS Sectors40 and 41 (the latter from 2021 July 23 to 2021 August 20). It was also observed during much of Cycle 2, but at 30 minutes cadence. However, during Sectors 14 and 15, this target was present in the target pixel file of TIC229960976, which *was* observed at 2 minutes cadence. The TESS Asteroseismic Science Operations Center used these data to construct a short-cadence light curve for TIC229960986. However, this light curve proved difficult to normalize, so we used only the data from Sectors 40 and 41 for our analysis.

These two stars were selected for manual review by a custom pipeline searching for high-amplitude peaks in the periodograms of all TESS short-cadence targets in a given sector. For TIC198781841, the roAp pulsations were flagged. For TIC229960986, the rotational frequency was flagged; human review uncovered a triplet of higher-frequency pulsations. The light curves and periodograms of the two stars are shown in Figure 1. As these stars are hot enough to reside within the instability strip, we concluded that these are genuine roAp stars and characterized their pulsation modes.

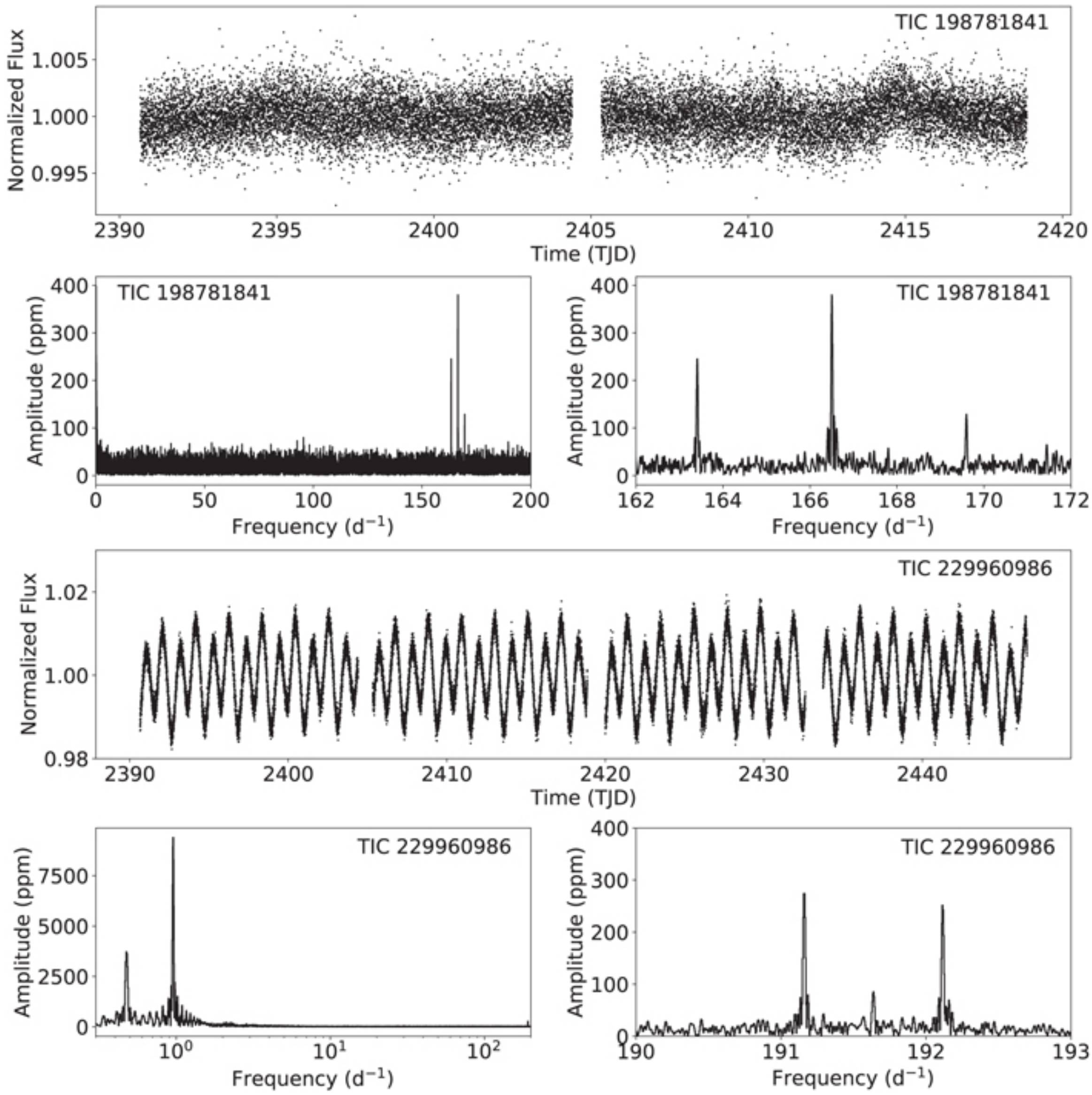


**Figure 1.** Light curves and periodograms for the two new roAp stars. Row 1: The 2 minutes cadence light curve from Sector40 for TIC198781841. Row 2: This light curve's periodogram from a Discrete Fourier Transform (DFT; see, e.g., Kurtz 1985), with a zoom into the roAp pulsations. Row 3: The 2 minutes cadence light curve from Sectors 40 and 41 for TIC229960986. Row 4: The periodogram of this light curve; the left panel is plotted on a semi-logarithmic scale to highlight the rotational frequency; the right panel shows the roAp pulsations.

## 3. Mode Identification

First, we identify the asymptotic (large) pmode frequency separation, as in Kjeldsen & Bedding (1995):

$$\Delta\nu_0 = \Delta\nu_{0,\odot}\sqrt{\frac{\bar{\rho}}{\bar{\rho}_\odot}} \qquad (1)$$

Here, $\Delta\nu_{0,\odot}$=135 $\mu$Hz, and $\bar{\rho}_\odot = 1.41$ gcm$^{-3}$. The mean stellar density $\bar{\rho}$ can be obtained from calculating the luminosity $L$ and then using the tables from Pecaut & Mamajek (2013) to determine the mass and radius for a given $T_{\mathrm{eff}}$ (obtained from the TESS Input Catalog; Stassun et al. 2019). To calculate $L$, we use the parallax and magnitude provided in the Gaia Early Data Release 3 (Gaia Collaboration et al. 2016, 2021).

### 3.1. TIC198781841

This star has a Gaia magnitude $m_G$ of 10.75 and a parallax of 2.21±0.01mas; the latter yields a distance of 452±2pc. Thus, the absolute magnitude is $M_G$ =2.474. Neglecting a small bolometric correction, we assume $M_G \simeq M_{\mathrm{bol}}$, which yields $L \approx 8.1 L_\odot$. For $T_{\mathrm{eff}}$=7725 ±250 K, the table by Pecaut & Mamajek (2013) suggests this is an A7/8V star, with a mass of ~1.8$M_\odot$ and a radius of ~1.75$R_\odot$, yielding $\bar{\rho} = 0.47$ gcm$^{-3}$. Thus, the asymptotic frequency separation $\Delta\nu_0 \approx 6.76$ day$^{-1}$ (78.2$\mu$Hz). The observed separation of the three peaks in the second panel of Figure 1 is 3.09 day$^{-1}$ (35.8$\mu$Hz)—nearly half the calculated $\Delta\nu_0$.

Unlike many recently identified roAp stars (see, e.g., Cunha et al. 2019), there exists no clear rotational signature within the span of the TESS data; the periodogram at low frequencies is consistent with noise. This indicates that this star could be a super-slowly rotating Ap (ssrAp) star (Mathys et al. 2020), with a rotation period longer than the time span of the TESS data set. Such non-rotationally split triplets, representing high-overtone pressure modes, often alternate between even and odd spherical degree $\ell$. Because high $\ell$ modes tend to be strongly geometrically canceled, the observed frequencies arise from alternating even and odd low $\ell$ values (e.g., {2, 1, 2} or {0, 1, 0}). These are high-overtone modes ($n \approx 20$, based on the large frequency separation; see, e.g., the Introduction of Otí Floranes et al. 2005).

### 3.2. TIC229960986

This star has $m_G$ =10.50 and a parallax of 2.27±0.04mas, corresponding to a distance of 441±8pc; this yields $M_G$ =2.28. Assuming again that $M_G \simeq M_{\mathrm{bol}}$, we obtain $L \approx 9.64\ L_\odot$. For TIC$T_{\mathrm{eff}}$=8150±145 K, the table of Pecaut & Mamajek (2013) suggests this is closest to an A5V star, with a mass of ~$1.9M_\odot$ and a radius of ~$2R_\odot$, yielding $\bar{\rho} = 0.34$ gcm$^{-3}$. The asymptotic frequency separation $\Delta\nu_0 \approx 5.69$ day$^{-1}$ (65.8$\mu$Hz).

Unlike TIC198781841, this star *does* have a clear rotational period of $P_{rot}$=2.0946± 0.0002 days, shown in the bottom panel of Figure 1. The equally spaced high-frequency triplet is split by the rotational frequency 0.4774day$^{-1}$ to within 1$\sigma$. This is a signature of an oblique dipole mode with $\ell$=1, as we expect $2\ell+1$ peaks for a given dipole $\ell$ mode, unless the $|m|$=2 components are within the noise. Since $P_{rot} \lesssim 0.1\Delta\nu_0$, the three frequencies cannot be alternating even and odd degree modes, as was the case for the previous star.

# 4. Conclusion

We have used TESS photometry to discover and characterize two new roAp stars. Large sky surveys such as TESS have considerably reduced the difficulty of detecting such stars. Future work will focus on obtaining spectra to identify chemical overabundances in these two stars and searching the TESS data for new pulsators.

*Facility:* TESS. -